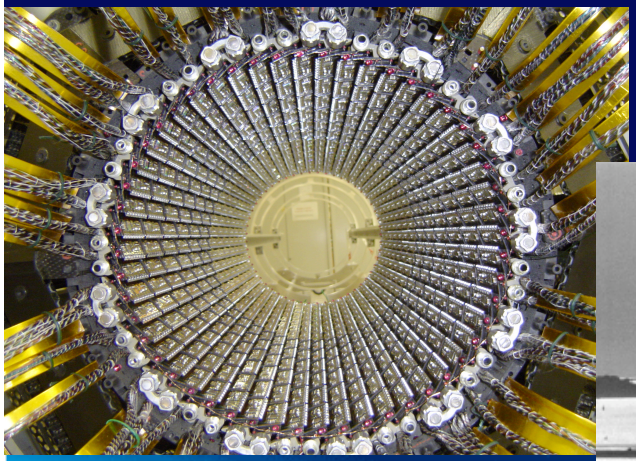
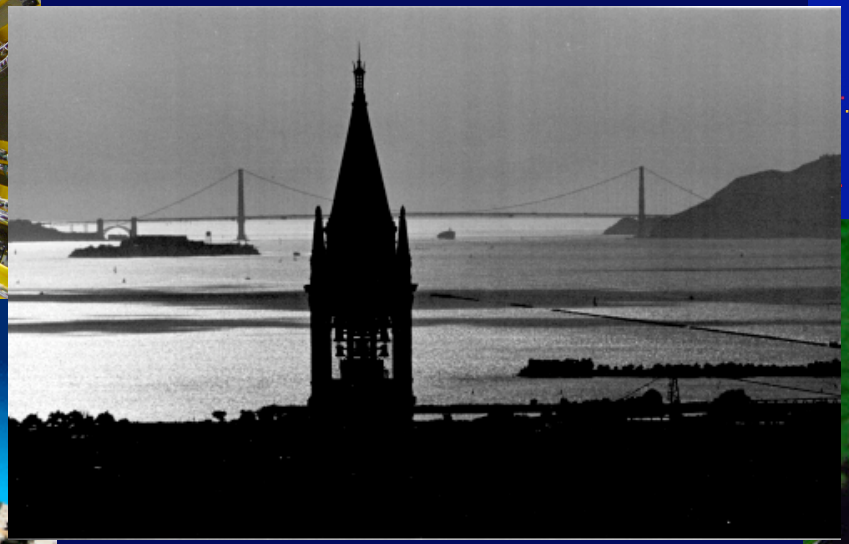
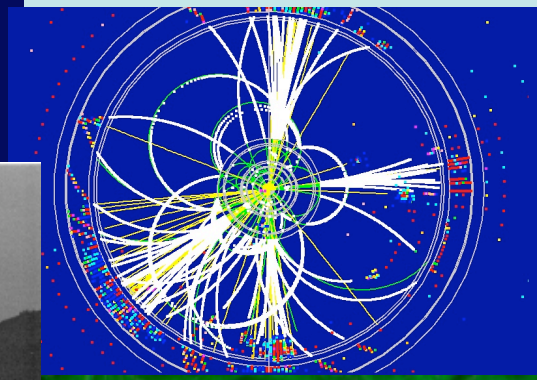
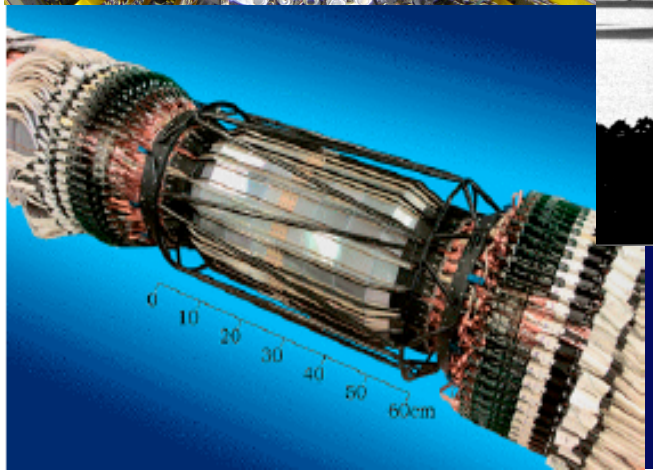
Experimental High Energy Physics

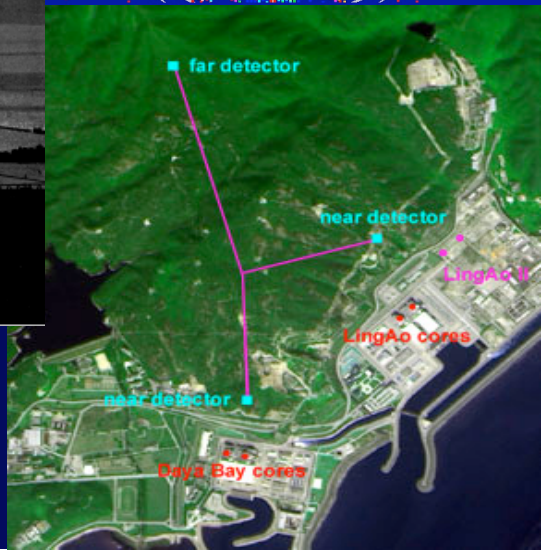
Beate Heinemann





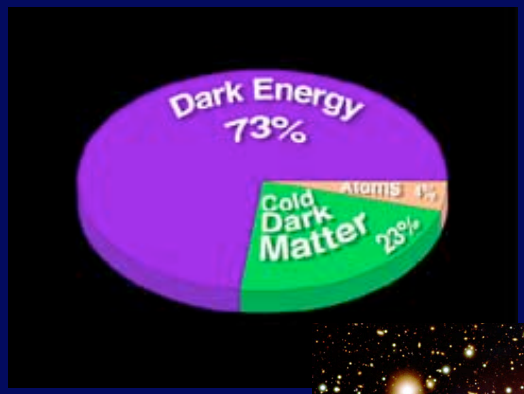


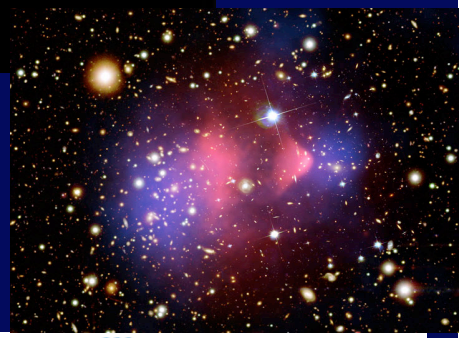


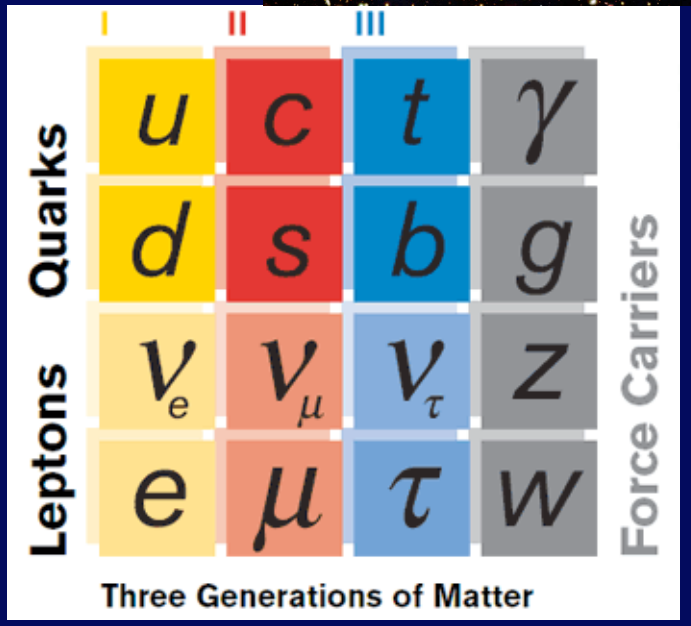


Fundamental Particles and Forces

- **4% of energy in Universe arises from Standard Model particles**
  - 3 generations with very different masses
    - why 3, why mass hierarchy?
  - 4 forces mediated by gauge bosons
    - Why do they have different strengths + were they the same at the Big Bang?
  - Where did all the anti-matter go?
    - Are neutrinos the clue?
  - Where is the Higgs boson?
    - Does it give mass to fundamental particles?
- **96% of the energy comes from unknown sources**
  - Dark matter and Dark Energy







Good reasons to believe that some answers will be found during your PhD!

Confusion among Theorists?

by Hitoshi Murayama, UC Berkeley

UC Berkeley HEP Exp. Faculty

Marco Battaglia
BaBar, ILC

Stuart Freedman
Neutrino physics

Bob Jacobsen
BaBar

Yury Kolomensky
BaBar, ILC, CUORE

Kam-Biu Luk
Neurino physics

arjorie Shapiro
CDF, ATLAS

James Siegrist
CDF, ATLAS

Beate Heinemann
CDF, ATLAS

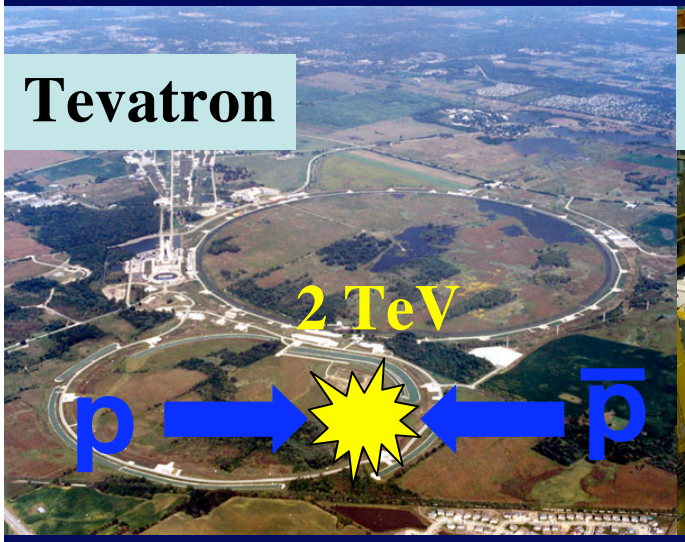
+ close collaboration with Lawrence Berkeley National Laboratory and faculty members from rest of the department

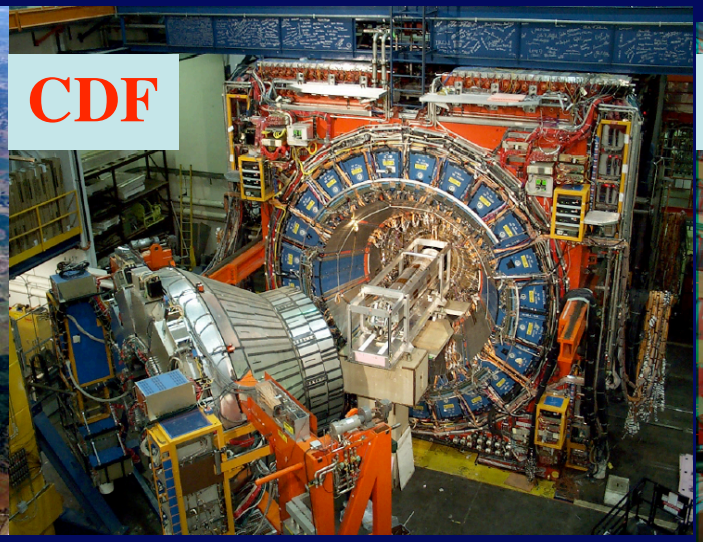
Experimental Programme

- **High Energy Frontier:**
  - **CDF/DØ** probe the highest energies and CP violation at the Tevatron (until 2009)
    - Shapiro, Siegrist, Heinemann (will take no new students on CDF/DØ)
  - **ATLAS** probes the highest energies at the LHC (start: this year)
    - Shapiro, Siegrist, Heinemann
  - **ILC** probes high energies with high precision (start: >2020)
    - Battaglia, Siegrist, Kolomensky
- **Matter vs Anti-matter, neutrino mass**
  - **BaBar** probes CP violation (matter-antimatter asymmetry) at SLAC (until 04/2008):
    - Battaglia, Kolomensky, Jacobsen
  - **KamLand** probes neutrino oscillations in Japan (until 2008):
    - Freedman
  - **DayaBay** will probe neutrino oscillations (>2009):
    - Luk
  - **CUORE/Cuoricino** probe neutrino masses (>now):
    - Freedman, Kolomensky

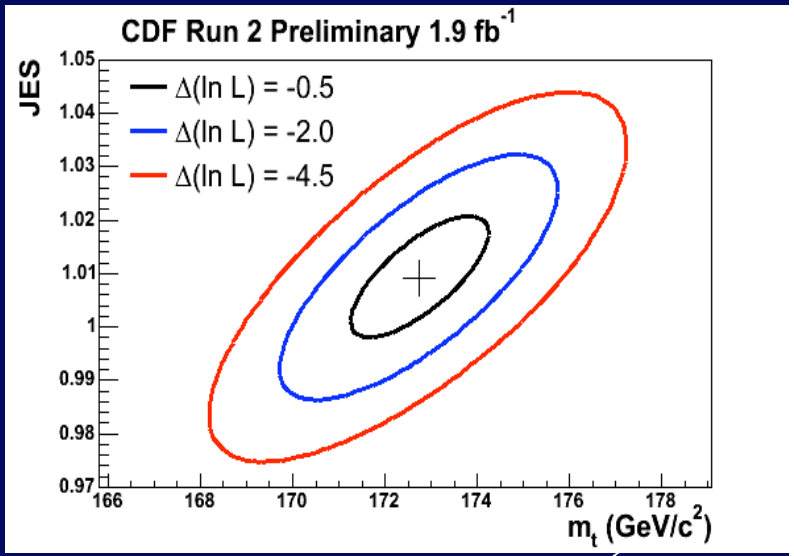
B. Heinemann
M. Shapiro, J. Siegrist

CDF and DØ

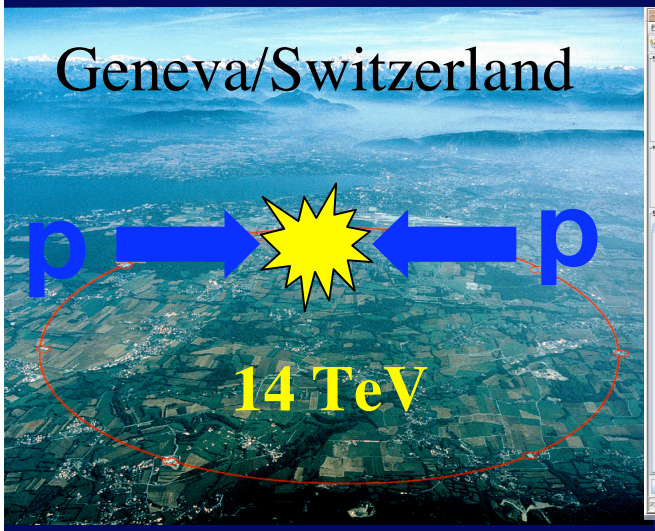


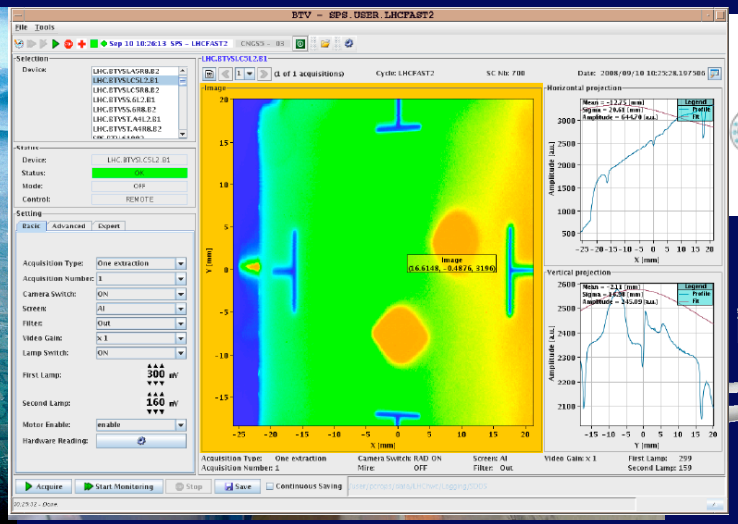


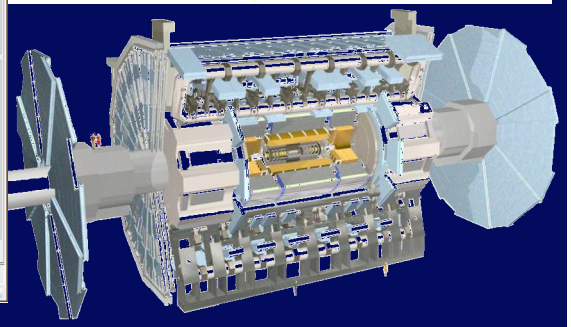
- **Collaborations of 700 physicists**
  - Major involvement of Berkeley in building, operating the detector and in physics analyses
- **Berkeley students made many unique and world's best measurements**
  - e.g. mass of the top quark
    - Tells us about the Higgs boson



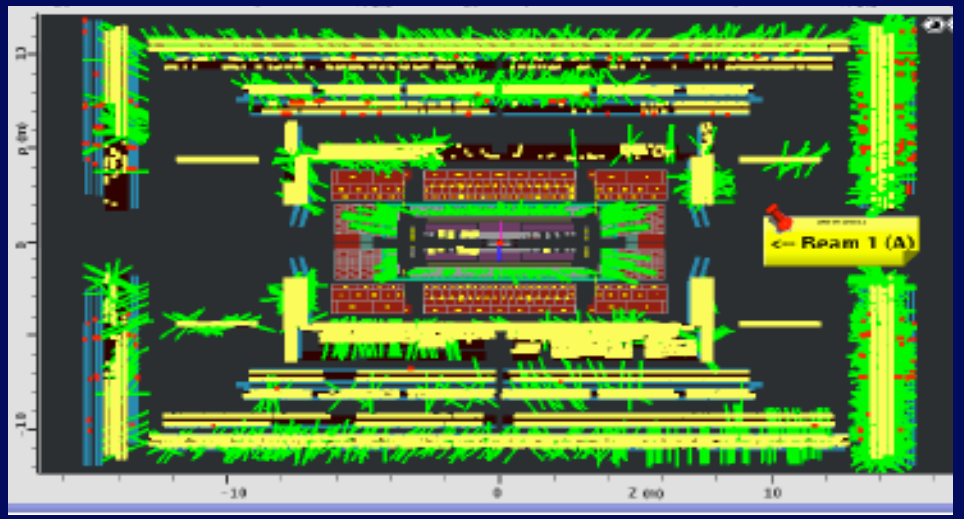
ATLAS at the LHC





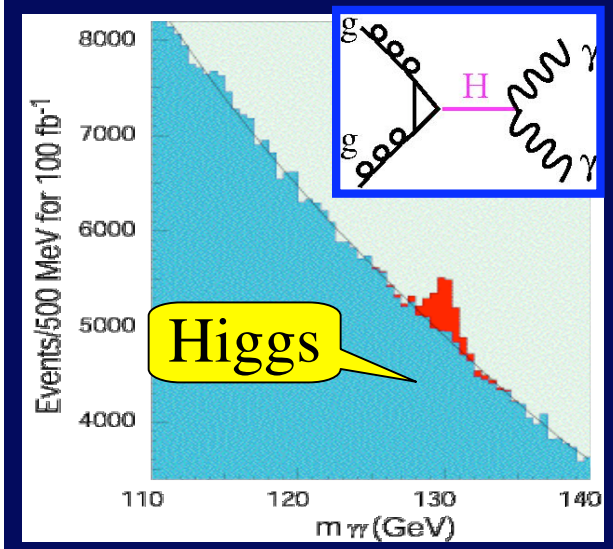


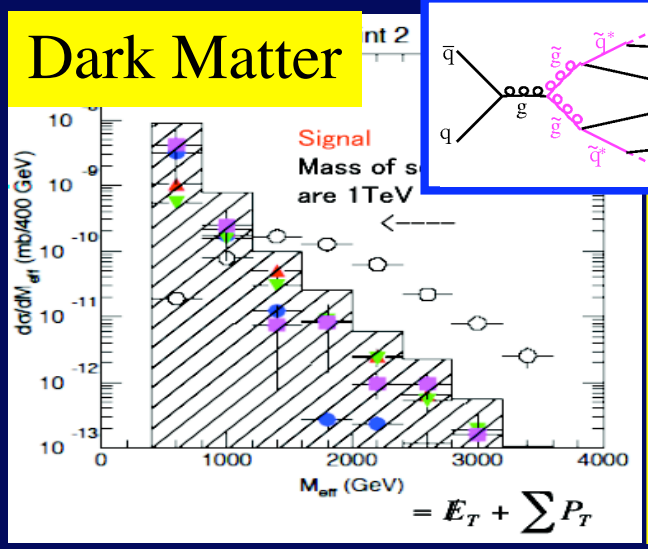
- **LHC will start 10 TeV collisions this year**
  - First beam Sep 14th 2008!
- **ATLAS Berkeley group has diverse talents**
  - Design tracking detectors
  - Software experts
  - Physics analysis expertise
    - Also from CDF/D0
- **ALICE group at LBNL**

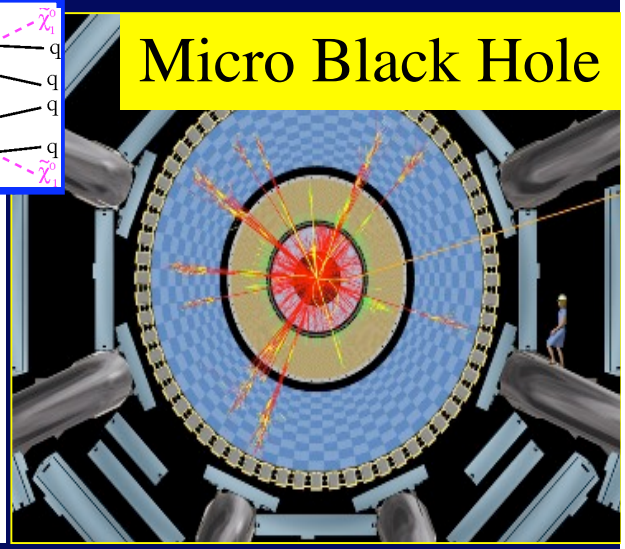


The advent of the LHC may revolutionize our understanding of physics

ATLAS: Physics Examples



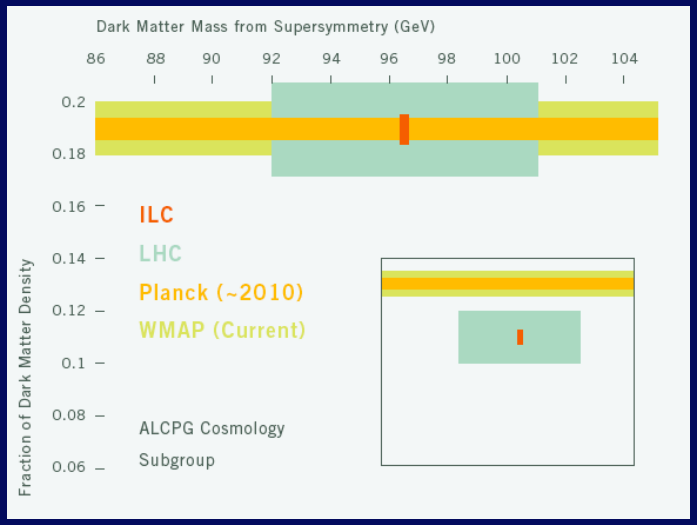


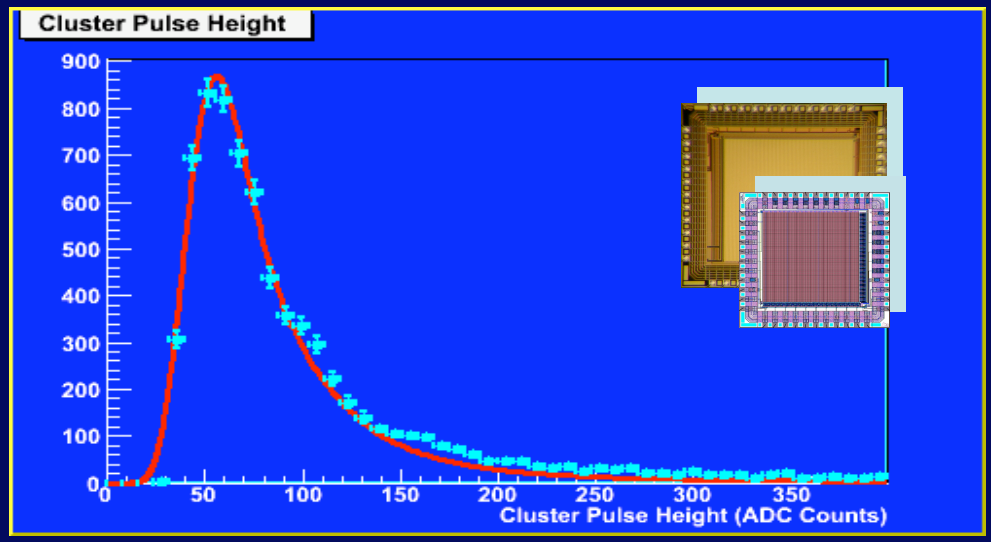


- **Discovery of the Higgs boson?**
  - Understand origin of mass
- **Discovery of Supersymmetry (SUSY)?**
  - Understand origin of Cold Dark Matter
- **Discovery of extra dimensions or black holes**
  - Understand weakness of gravity
- **Understand the state of matter in early Universe**
  - Quark-gluon Plasma
- **….or the unexpected!?!**

B. Heinemann
M. Shapiro
J. Siegrist

High Energy Frontier: Future





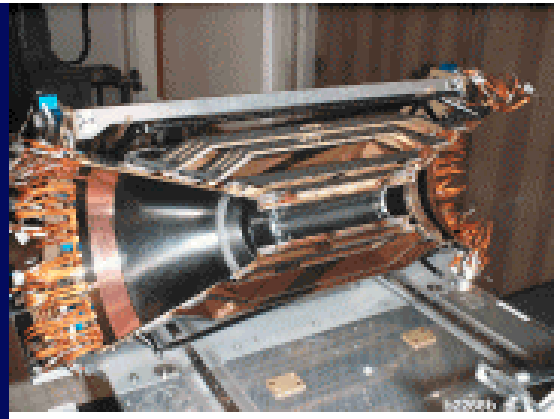
- **International Linear Collider: e^+e^- coll. at 0.5-1 TeV (~2020?):**
  - Vital to really understand high energy physics
  - Berkeley active in R&D for beam instrumentation and tracking detectors & physics feasibility studies
- **Super-LHC (start ~2016):**
  - Extends the capabilities of LHC (higher collision rate)
  - R&D for tracking detectors ongoing in Berkeley
- **Get cutting edge hardware experience in R&D phase**
  - Then move on to running experiment for thesis topic

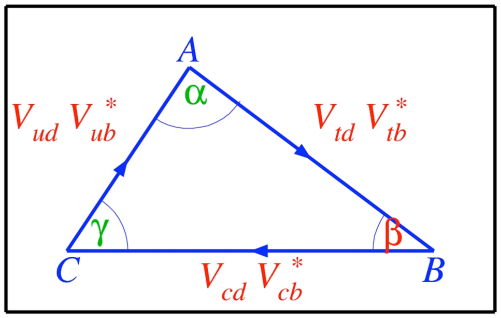
M. Battaglia
Y. Kolomensky

M. Battaglia
Y. Kolomensky

BaBar

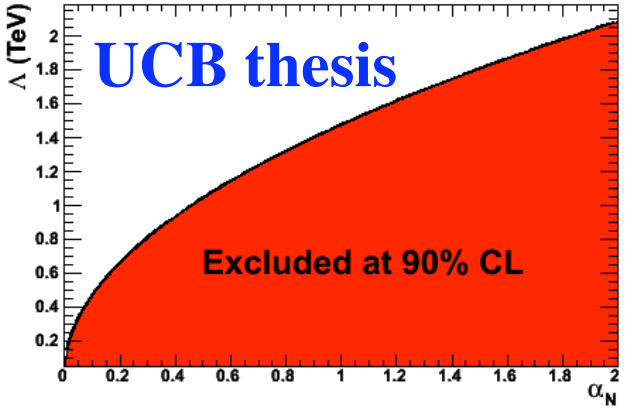
- **PEPII collider at SLAC:**
  - e+e- collisions at $\sqrt{s}$=10.6 GeV [Y(4s)]
    - Produce pairs of b-quarks
    - 2008: also ran on Y(3s) and Y(2s)
  - Berkeley heavily involved in design, construction and operation of Silicon Vertex Tracker
  - Stopped running last year
- **Physics goals e.g.:**
  - Precision measurement of unitarity triangle
    - Understand quark sector of SM
  - Search for new physics contributions indirectly by precision measurements in b-quark sector
  - Direct searches for exotic new physics, e.g. light Higgs bosons or axions, lepton-flavor violation





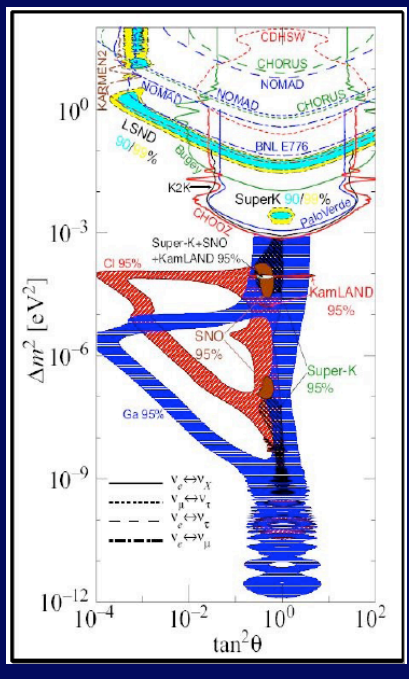
UCB thesis:

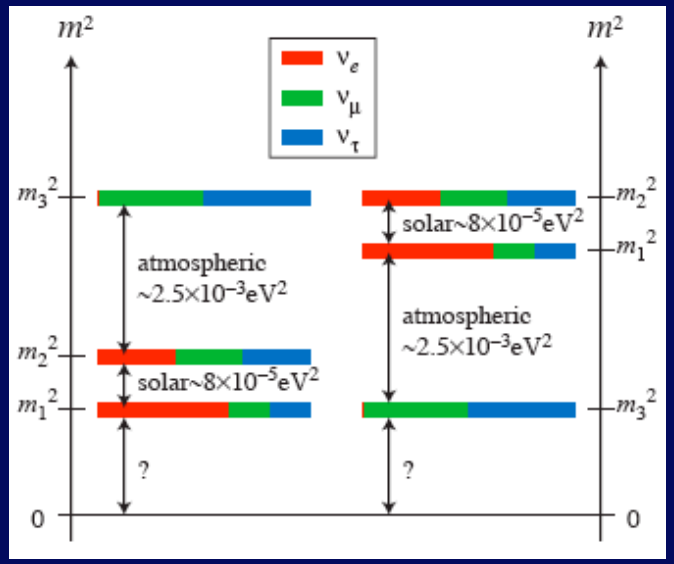
$\alpha = 84^{+30}_{-7}{}^{o}$



What are Neutrinos telling us?

- **Neutrinos oscillate: $m_\nu > 0$**
  - Super-Kamiokande 1998
  - KamLAND, K2K, SNO
- **That raises more questions than it answers:**
  - **How do they mix (θ_{13}) ?**
    - Mixing between 1st and 3rd generation still unknown
    - Why is the mixing so different to quark sector?
  - **Is there CP violation in the neutrino sector?**
    - Does that maybe explain the matter-antimatter asymmetry?
  - **Are they their own antiparticle?**
  - **What are the actual mass values and why are they so small?**
    - Do their small masses tell us anything about very high energies and unification?

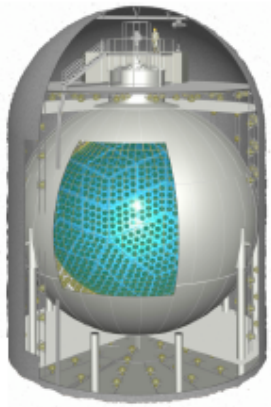


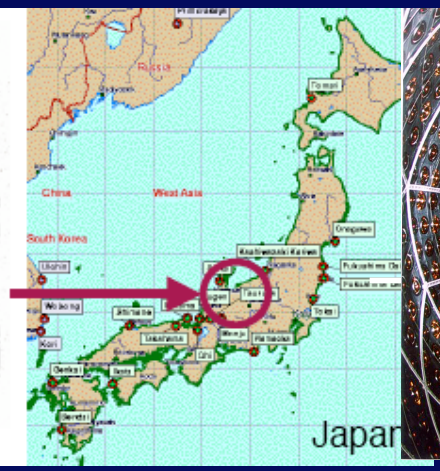


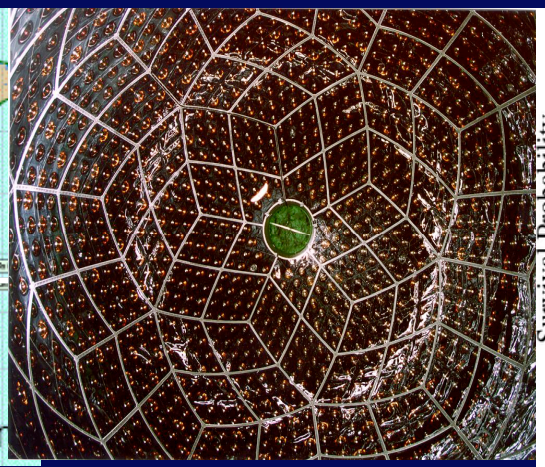
at least one $m_\nu > 55$ meV

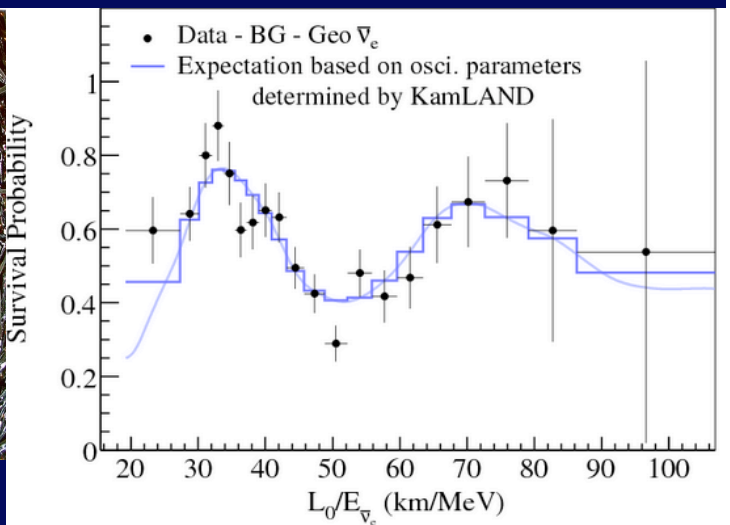
S. Freedman

Neutrinos @ KamLAND

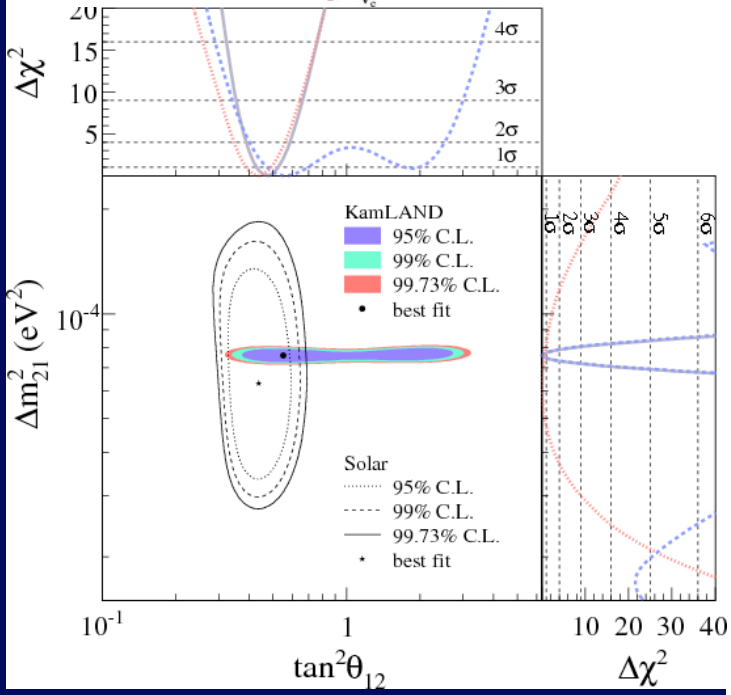








- **Reactor neutrino experiment**
  - **Surrounded by many Japanese reactors that produce ν_e**
    - **Measure rate of ν_e disappearing**
  - **Recent results:**
    - **Most direct evidence for ν_e oscillations**
      - **Together with SNO constrains one of the mixing angles: θ_{12}**
    - **Also measures solar and geo neutrinos**
      - **Many interesting results currently in preparation**
  - **Future:**
    - **exploit improved sensitivity at low E**



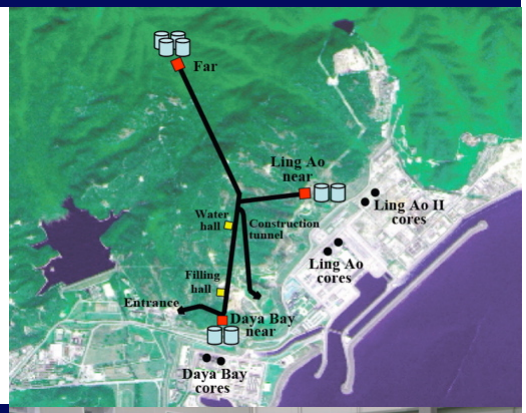
K.B. Luk

Neutrinos @ Daya Bay

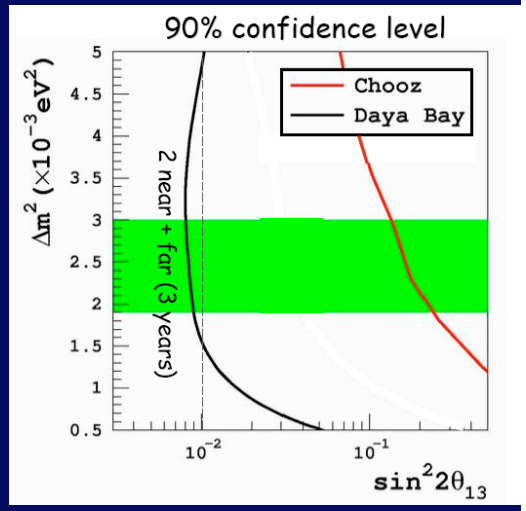
$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} 0.8 & 0.5 & U_{e3} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} ?$$

$$= \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{12} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} e^{i\delta_1} & 0 & 0 \\ 0 & e^{i\delta_2} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Majorana

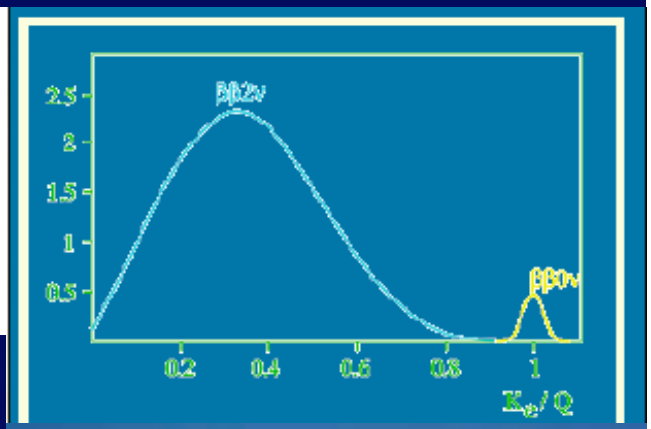


- **Reactor experiment near Hongkong**
  - Complementary to e.g. T2K and Nova
- **Goal: measure mixing angle θ_{13}**
  - Determines feasibility of measuring CP violating phase δ
- **Civil construction has started last year**
  - Tunnel building started Feb. 19th 2008
- **Data taking**
  - Summer 2010: near halls
  - Summer 2011: all 8 detectors
- **Opportunities to work on construction and data analysis during your PhD**

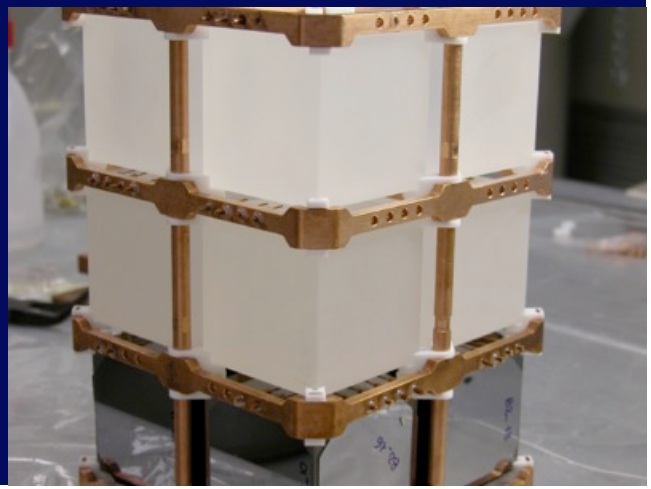


CUORE: ββ-Decay without ν's

S. Freedman
Y. Kolomensky

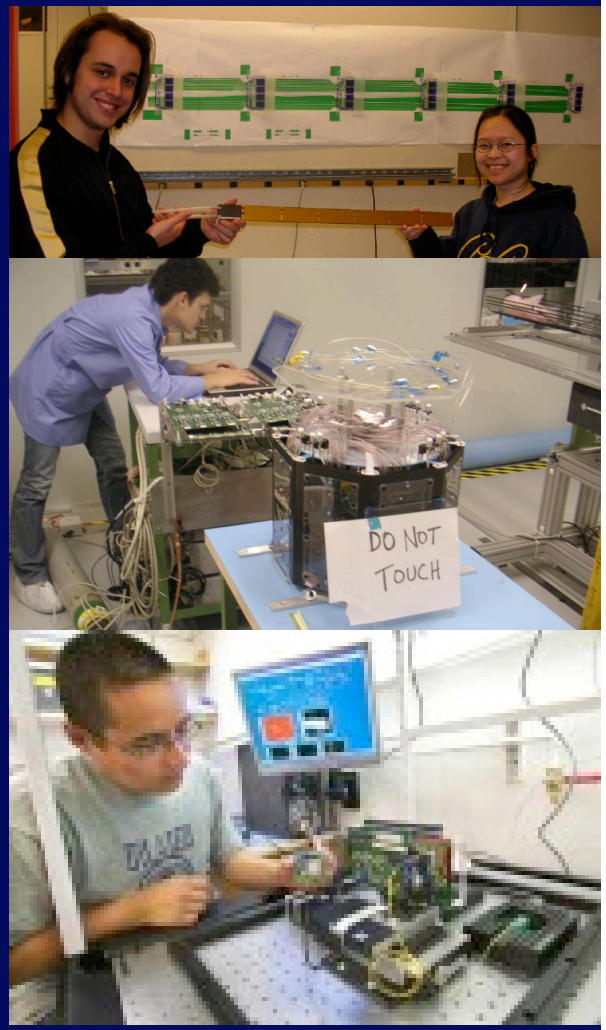


- **Neutrinoless ββ-decay**
  - ββ(2ν):Nucleus (A,Z) →(A,Z+2)+2e⁻+2ν$_e$
  - ββ(0ν):Nucleus (A,Z) →(A,Z+2)+2e⁻+0ν
    - if neutrinos are there own anti- particles
    - Direct measurement of ν-mass
- **Status:**
  - Cuoricino run with 40 kg detector (finished)
  - Cuore starts in 2012 with 1000 kg detector
    - Sensitive to m$_\nu$~100 meV
  - Cuore-0 starting 2010
    - 1 of 19 Cuore towers
- **Opportunity to work on construction and data analysis**



Conclusions

- **Start of Large Hadron Collider and new neutrino experiments**
  - Particle Physics faces very exciting times
- **Berkeley HEP program is rich and diverse**
  - pp collisions, e^+e^- collisions, neutrino experiments
- **Excellent opportunities for**
  - Detector hardware development
  - Detector operation
  - Physics analysis
- **Inspiring connection between HEP experimentalists and theorists, cosmology, nuclear physics:**
  - Uniquely placed due to tight connection to US Laboratory (LBNL) with large resources (see tour on Friday)



Contact us and we'll tell you more!